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EVOLUTIONARY-DRIVEN AGENT ADAPTATION IN OPTIMIZING SEARCH: INITIAL RESULTS

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Objectives

This research was an initial exploration into the ability of a team of autonomous software agents to be effective in unknown and changing optimization environments by evolving to use the most successful algorithms at the points in the optimization process where they will be the most effective. The goal of this project was to define the core framework and methodology for agent-based adaptive optimization strategies using an evolutionary approach at the strategic, rather than solution level – where the strategies of agents in the team (the decisions for picking, altering, and inserting a solution) evolve over time. As one application of this approach, individual solutions are tours in the familiar combinatorial optimization problem of the traveling salesman. As another application, an initial 3 dimensional layout problem is defined. The work also sets the stage to begin investigating how teams coordinate.

Accomplishments/New Findings

There are several factors motivating a strategy evolution approach to solving complex optimization problems in dynamic environments. Firstly, because changing variables means that the structure and dimension of the design space changes over time, a *flexible representation* of solutions is needed. Because solution structure is not static, it follows that the *strategies for generating solutions should not be fixed* either, but should instead adapt to the design space as it changes. Also, since the topology (the constraints and objectives) of the problem design space are constantly changing, it is also *impractical to rely on a single algorithm or strategy*, especially since the more complex the algorithm, the more fine-tuning is needed to make it effective on a specific instance of the problem.

In the evolutionary multi-agent systems (EMAS) framework, we achieve adaptive strategy application by allowing solution strategies to evolve over the course of the optimization. Each strategy for generating new solutions is embodied in a single, autonomous agent. The agents (strategies) work in parallel to produce new solutions and explore the design space, thus eliminating reliance on a single algorithm. In addition, agents cooperate by sharing the results of their work in databases or 'memories', to which all other agents have access to. The shared memories may contain partial and working solutions in addition to complete solutions and while the quality of solutions generated drives the evolutionary process of the agents, the agents are not endowed with *a priori* knowledge of the solution structure. Thus, changing the structure (the number of variables) of the solution does not adversely affect the agents' ability to create new solutions.

As agents create new solutions and improve old ones, they are rewarded or punished for their successes and failures. The reward or punishment is translated into a change in the agent's fitness. Over the course of the optimization, agents may reproduce if they have been successful (i.e. if they have a high fitness), or may be removed from the population if they have not. Thus, genes in the agents' chromosomes representing pieces of an entire strategy (either learned or inherited) are passed from one generation to the next through genetic operators like crossover and mutation. The result is a constantly changing team of heterogeneous strategies that produces – as a byproduct of its actions – a continuously improving set of solutions in the shared memory.

The results present a convincing argument for the evolution of agents in a team at the population level. Decisions have proven to be a useful genetic property of agents in such an evolutionary setting. The evolutionary teams evolved to generate better solutions than the base algorithms alone. We have also shown that the strength of the EMAS algorithm lies in its ability to evolve the best team of agents dynamically. Evolution and activation within this team results in solutions that are better than simply running the same number of algorithms randomly on a similar set of solutions. We thus argue that the

use of evolutionary agents to determine the best solution strategies dynamically is a strong approach to adaptive optimization. Decentralizing the strategy selection process and allowing strategies, rather than solutions, to progress in an evolutionary manner means that a much broader range of design and optimization applications, including layout, scheduling, and manufacturing planning, can be confronted in the face of design space uncertainty and change. Another strength of the EMAS algorithm is as a predictive or learning guide for which set of algorithms or strategies should or should not be employed and when. Utilizing EMAS in this way, at least as seen on a static case of the TSP, has been shown to lower computation time while maintaining or even improving solution quality.

As a next step we have created a foundation to explore EMAS on a complex engineering design problem, the 3 dimensional layout of a product. We have implemented 4 optimization algorithms: simulated annealing, extended pattern search, genetic algorithm, and the Powel's Method local search. EMAS determines which solution strategies the agents will use at any time, and parameters for those algorithms. We have tested the approach on a simple cube packing problem and the layout of an engine compartment for a vehicle. Initial results are quite promising and will be thoroughly analyzed and compared to both the TSP findings, and the results of individual algorithms.

We have also begun to use EMAS to consider how teams effectively communicate, what strategies work best and how that influences EMAS results

Personnel Supported

Faculty: Prof. Jonathan Cagan, Prof. Kenneth Kotovsky
Graduate students: Lindsay Hanna (full support: Mechanical Engineering PhD student)

Publications Relevant to Grant

Hanna, L., and J. Cagan, "Evolutionary Multi-Agent Systems: An Adaptive Approach To Optimization In Dynamic Environments," *ASME Journal of Mechanical Design*, **131**(1):011010-1-8, 2009.

Hanna, L., and J. Cagan, "Evolutionary Multi-Agent Teams for Adaptive Optimization," *Agent 2007 Conference on Complex Interaction and Social Emergence*, November 15-17, Chicago, 2007.

Hanna, L., and J. Cagan, "Evolutionary Multi-Agent Systems: An Adaptive Approach To Optimization In Dynamic Environments," in: *Proceedings of the 2008 ASME Design Engineering Technical Conferences: Design Automation Conference*, *DETC2008-49211*, New York, August, 2008.

Additional papers are in progress that will acknowledge grant.

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14. ABSTRACT
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